Request for Economic Stimulus Funds

<u>Concept</u> <u>Proposal</u>

1. Submitters (Name of Workgroup & Chair/Co-Chairs):

Energy and Sustainability Group (Dr. Doug Whitlock and Dr. James Tracy)

2. Project Title:

Pilot Study of CO_2 Sequestration by Cycling Solvents Scrubbing Technologies

3. Project Partners (Known or Anticipated):

Western Kentucky University, 3H Company, and Owensboro Municipal Utility Power Plant (OMU)

4. Project Background & Purpose (Justification for Project):

Since 2002, the Institute for Combustion Science and Environmental Technology (ICSET) at Western Kentucky University (WKU) has been participating in an ongoing carbon dioxide (CO_2) sequestration research project using an aqueous ammonia scrubbing technology with China and other countries. CO_2 produced from combustion sources, such as fossil-fuel fired power plants, is captured from the flue gas. The CO_2 reacts with aqueous ammonia to form ammonium bicarbonate (ABC), which can act as a "CO_2 carrier" to "transport" CO_2 from the combustion of fossil fuels to soil structure and crops in the farm lands since it is water soluble. Firstly, ABC is an economical and environmentally acceptable nitrogen and carbon fertilizer. After biological assimilation and metabolism in crops, a considerable amount of the carbon is absorbed by the plants with increased biomass production. Secondly, the majority of the unused carbon source percolates into the soil as water-soluble bicarbonates where it moves into alkaline aquifers to form carbonate salts of calcium ($CaCO_3$) and magnesium ($MgCO_3$). These carbonates are environmentally benign and water insoluble salts. They are found in most natural caverns.

WKU scientists have investigated the fate of carbon distribution after the ABC fertilizer is applied to soil. It was found that a considerable amount (up to 10%) of the carbon source is absorbed by plants with increased biomass production. The majority of the unused carbon source (up to 76%) percolated into the aquifer to form stable carbonates. Of those 76% carbon, up to 88% was in the form of insoluble salts (i.e., $CaCO_3$) in alkaline soils. Generally speaking, alkaline soil better captures and stores carbon. This indicates that alkaline soil has a greater potential for storing carbon using ammonium bicarbonate.

In summary, the purpose of the CO_2 sequestration project would be to 1) evaluate the market potential resulting from the establishment of the economic feasibility and environmental desirability of land application of a fertilizer, Long-effect ABC (LEABC) or ammonium carbonate (AC), thus strengthening and stabilizing agricultural production; 2) reduce the emission of CO_2 to the environment, which will provide the electric power generation industry with carbon credits for sale and/or trade through the application of a practical technology for existing coal-burning power plants.

Thus, we propose to undertake a thorough research program that will include the following tasks:

- Establish a pilot-scale integrated self-supporting system with a fertilizer production line in a power station,
- Study the chemical kinetics and thermodynamic equilibrium of the ABC or AC synthesis process occurring between carbon dioxide and ammonia (or ICSET's solvents) in real flue gas conditions,
- Overcome the technical hurdles to optimizing the ABC or AC synthesis process (fertilizer stabilizer and long-term effectiveness additive),
- Investigate the fates of major pollutants of coal-derived flue gas, such as SO_2, NOx and Hg, in the ABC application
- Develop a testing protocol to determine the mass balance for carbon following the use of stabilized ammonium bicarbonate or ammonium carbonate as a fertilizer,
- Obtain first-hand data on the percentage of carbon percolating down to and being

sequestered in soil and ground water,

- Develop an understanding of the release mechanisms for carbon under various field conditions,
- Determine the optimum pH range of soils to be used for carbon capture,
- Find the optimal conditions for soil and groundwater to capture carbon and form stable carbonate salts, such as calcium carbonate,
- Establish a model for carbon transfer from ABC or AC to the terrestrial ecosystem.

5. Project Description (General Goals & Implementation Strategies):

Aqueous ammonia scrubbing is a very promising technique for CO_2 sequestration in flue gas. However, CO_2 removal efficiency is limited if only ammonia scrubbing is used because flue gas has the characteristics of low CO_2 concentration, atmospheric pressure, high temperature and high volume flow rate. Continuous operation with a large capacity for CO_2 sequestration is highly desirable for practical application in power plants. In this proposal, a conceptual process design, which combines aqueous ammonia scrubbing, CO_2 regeneration, product formation and separation of ammonium bicarbonate/carbonate, is proposed. **Phase I** will focus on experiments in a scaled-down onsite slipstream reactor. The pilot-scale reactor system (0.6MW) will be built on site at OMU and a series of experiments will be conducted in this phase, in order to come up with a detailed phase diagram for the CO_2-NH_3-H_2O or CO_2-solvent-H_2O reactions and to optimize conditions to produce ABC or other products. Additives will be used to produce LEABC during this process (CO_2-NH_3-H_2O) to evaluate their function at shifting the phase diagram and product distribution. The influences of solution makeup, solution recirculation rate, temperature, rotating speed, residence time, as well as flue gas components (SO_2, NOx, Hg) on CO_2 removal efficiency and solid products will be investigated. The fates of major pollutants in the flue gas atmosphere, such as SO_2, NOx and Hg will be investigated. The three-phase diagram will be developed in this phase. The modified phase diagram will be the basis for application and conversion of the proposed system to a commercial scale.

This slipstream (0.6 MW @ 25470 SCFH) will be setup downstream of a wet-FGD system, close to open space (10x8 sq feet) near the installed underground re-circulation pump underground at OMU. A long section of heat exchanger piping (*OD: 24 in*), which functions as pre-heat exchanger and moisture rejector, induces flue gas from the wet-FGD outlet on the 5th floor into this slipstream reactor that resides on the ground floor. Two towers are integrated into an absorber-regenerator island to capture and concentrate CO_2 stream from the induced flue gas stream. Flue gas firstly enters into the absorber (either packed bed or spray nozzle bed, *24 inch OD with 10ft height*), where it meets the NH_3 effluent solution (*178 lb/hr, 30% in solution, water supply: 418 lb/hr*) to form NH_3HCO_3 or $(NH_4)CO_3$. In order to enhance the utilization of NH_3, a re-circulation cycle inside the absorber will be setup using a re-circulation pump. The temperature of the absorber will be 25^{o}C. The residence time of the flue gas with NH_3 will be 5 seconds. After settling, the NH_3HCO_3 or $(NH_4)_2CO_3$ solution will either be used to manufacture the NH_3HCO_3 fertilizer (*the CO_2 capture is around 410 lb/hr)* or sent to the regenerator. Inside the regenerator *(24 inch OD with 10ft heigh*t), the NH_3HCO_3 or $(NH_4)_2CO_3$ effluent solution will be heated using flue gas to generate a purified CO_2 stream after the NH_3 is rinsed using injected water. The temperature of the regenerator will be 80^{o}C. A reboiler will further assist decomposition of NH_3HCO_3 or $(NH_4)_2CO_3$. An additional NH_3 rejector is equipped downstream of the regenerator to further reduce NH_3 leakage into the atmosphere. In order to reduce the system setup capital costs, the flue gas and purified CO_2 stream will be directly vented into the atmosphere in this slipstream demonstration.

Based on the most recent CO_2 credit price from the CDM project in September 2008 (U.S. $25/t), a newly setup carbon dioxide sequestration system with capacity equivalent to that of a 600 MW coal-fired power plant could generate net profits of US $3000/hr. Moreover, production of ammonium bicarbonate could generate additional profits, which based on the June 2008 market price would be a wholesale price of US $100 - $132 /t in China. The daily production of ammonium bicarbonate could be as high as about 4200 ton (based on an hourly rate of 173 ton which assumes 100% capture efficiency) for a 600 MW coal-fired power plant. This estimated economic analysis indicates that the proposed CO_2 capture technology using ammonia is economically competitive.

Phase II: Study impacts of ABC fertilizer on plant growth (compared to ammonium nitrate, urea).

With the agreement of co-operation by the Department of Agriculture at Western Kentucky University, the scope of the Phase II project has been increased to encompass two different geographical areas with substantially different soil types and structures. This adds to the validity of results obtained, not only by having more plots of land and crop samples under evaluation, but also by diversifying the soil types and micro-climate variables. As a result, data resulting from this study will have greater applicability for evaluating the benefits of application of ABC. The Phase II CO_2 sequestration project sets out to evaluate the commercial-ready technology associated with the utilization of ABC fertilizer that will be obtained by aqueous ammonia scrubbing of flue gases produced by power plants in Phase 1. In this evaluation, different ABC samples generated at different power stations will be applied to a total of six individual test plots, each 40 feet by 30 feet in size. Each test plot, three of which are to be located on the Heritage Farm properties and three of which are to be located on the Western Kentucky University Farm, will be planted with a combination of three different crop types in alternate rows. These crop types, namely corn, soybeans and alfalfa are well suited to production in Kentucky and therefore have commercial relevance (power plant may have opportunity to select a different crop to fit their commercial relevance). All of these tests will help access the potential value of ABC fertilizer to the farmer/producer, as compared to established commercially available sources of nitrogen fertilizer. If the ABC product can be shown to produce a larger profit for farm producers, enhance the value of their production resources and not result in environmentally unacceptable consequences, a substantial demand will certainly be created for this fertilizer.

6. Project Team (Project Manager(s), Content Experts, Instructional Designers, etc.):

Dr. Wei-Ping Pan (Material Balance), Director of ICSET; Dr. Yan Cao (Engineering Design), Assistant Director of ICSET; Dr. Chin-Min Cheng (Environmental Engineering), Manager of ICSET, Dr. Liang Hu (Chemical Reaction), President of 3H Company; and Mr. Kevin Frizzell (Power Plant Management), Plant Manager of OMU

7. Project Budget & Amount of Economic Stimulus Funds Requested:
ICSET will contribute available facilities, instrument and lab space as primary sources to develop the proposed project, except a few facilities which need to be newly setup. Major funding will be used to support high-quality team to conduct research and development on the proposed concept and process integration. In Year 1, the estimated cost is $700,000 which including (1) Team's salaries and fringes: PI, CO-PI, research Associates, Technicians and Specialists; totally 10 persons; (2) Newly setup facilities include CO_2 capture pilot reactor (3) Materials for proposed tests (gas and chemicals). In Year 2, the estimated cost is $500,000 for process integration and demonstration. The total cost of this project is **$1,200,000**. **Economic Impact:** Our entire economic future may depend upon whether or not we are able to development and implement cost effective multi-pollutant and CO_2 emissions control technology for coal-fired power plants. Given the current trajectory of emissions regulation, without the implementation of technology as described in this proposal, our region's electric utility rates will most certainly continue to rise. Significantly higher utility rates will substantially increase the cost of living for everyone in our region; and worse yet, it will become increasingly difficult, up to the point of impossible, to attract and retain companies in our region. In fact, without this technology, over time, we stand to lose most of our manufacturing jobs in the region. In this proposal, our experienced and internationally recognized research team at the WKU Institute for Combustion Science and Environmental Technology are proposing an extremely effective multi-pollutant and CO_2 emissions control technology for coal-fired power plants. On behalf of everyone in our region in support of maintaining our relatively low electrical

utility rates, we are asking for your support to enable us to develop, test and implement the proposed solution.